Abstract Title Page

Title: Does Cognitive Strategy Training on Word Problems Compensate for Working Memory Capacity in Children with Math Difficulties?

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Abstract Body

Limit 4 pages single-spaced.

Background / Context:

Recent intervention studies directed to improve problem solving accuracy in children with math difficulties (MD) have found support for teaching cognitive strategies. Several studies have found that verbal strategy instruction (e.g., Montague, 2008, Xin, 2008), as well as visual-spatial strategies (e.g., Kolloffel, Eysink, de Jong, & Wilhelm, 2009; van Garderen, 2007) enhance children's math performance relative to control conditions (see Baker, Gersten, & Lee, 2002; Gersten et al., 2009; for reviews). For example, in a randomized control group design, Fuchs et al. (2003) taught problem solving methods to children with MD and found that cognitive strategies (schema based instructions) improved problem solving accuracy (effect sizes ranged from 1.16 to 1.18 depending on the transfer measure). Additional successful strategy models have included diagramming (van Garderen, 2007), identifying key words (e.g., Mastropieri, Scruggs, & Shiah, 1997), and meta-cognitive strategies (e.g., Montague, 2007; see Gersten et al., 2009, Xin & Jitendra, 1999, for reviews). These studies strongly suggest that the training of cognitive strategies facilitates problem solving accuracy in children with MD.

Despite the overall benefits of strategy instruction in remediating word problem solving word difficulties, the use of strategies for some children with MD may not always be advantageous. From an aptitude-treatment perspective, not all children with MD may be expected to benefit from strategy training. In this study, we hypothesize that the availability of ample working memory resources is an important precondition in determining whether strategy training will be successful. This is because strategies are resource demanding. As a consequence, children with relatively smaller working memory capacities (WMC) may be easily overtaxed by certain strategies, which may even lead to poor learning outcomes after training. This is because word problem solving is an activity that draws upon WMC to a considerable degree. Because children with MD experience working memory difficulties (e.g., Fuchs et al., 2011; Swanson, 2010), their poor problem solving skills plus their low WMC may have direct consequences on the effectiveness of cognitive strategy interventions. In contrast, children with MD who meet a certain threshold of (yet to be determined) WMC would have spare working memory resources to benefit from cognitive strategies. Thus, individuals with MD but relatively higher WMC are better able to utilize cognitive strategies than children with lower WMC. This is because strategies rely on declarative representations and serial cognitive processes that require large amounts of WMC (e.g., Anderson, 1987), and the utilization of cognitive strategies that have been recently acquired imposes demands on WMC. In the context of this study, we define working memory as a processing resource of limited capacity that is involved in the preservation of information while simultaneously processing the same or other information (e.g., Baddeley & Logie, 1999; Unsworth & Engle, 2007).

Purpose / Objective / Research Question / Focus of Study:

This study addresses the question: What role does working memory capacity (WMC) play in strategy outcomes for children with MD? Four prediction models can be applied to strategy training outcomes for children with MD: (a) WMC as a limiting factor, (b) basic skills, (c) general resource, and (d) compensatory. The limiting WMC factor model suggests that children with lower WMC are less likely to benefit from strategy conditions than children with relatively higher WMC. Thus, children with MD vary in their responsiveness to strategy instruction and this is predicated on their WMC. In contrast, the basic skills model suggests that if declarative knowledge is intact (e.g., reading comprehension, and computational knowledge are in the

average range), strategy instruction provides a helpful procedure to solve word problems without making demands on WMC. This model suggests that cognitive instruction provides additional information over control conditions when basic skills (e.g., calculation, reading) are intact. For example, children with MD benefit from strategy instruction because they are less efficient in calculation and general problem solving than children without MD. Thus, strategy instruction interacts with math or reading ability, and not WMC. In contrast, the general resource model hypothesis predicts that individual differences in WMC are related to solution accuracy regardless of treatment conditions. The resource model predicts that because WM as a general system underlies several problem solving tasks, WMC has a general effect (nontreatment specific effect) on problem solving outcomes. Finally, the compensatory model suggests that WM interacts with treatment outcomes. Cognitive training is viewed as reducing processing demands on children's problem solving, and therefore freeing additional resources to solve problems. The compensatory model predicts that children with low WMC are more likely than those with relatively higher WMC to place a greater reliance on strategy conditions.

The first hypothesis predicts an interaction in favor of the high WMC group, the second predicts no significant involvement of WMC in strategy outcomes; the third predicts a main effect for WMC but no interaction with strategy conditions; the fourth predicts a significant WMC x cognitive strategy interaction in favor of children with low WMC.

Setting:

Children were drawn from 22 3rd grade classrooms. Children in the treatment conditions were provided instruction in small groups during math time and were instructed in a class or library in the same school setting. All children in the study participated with their peers in their home rooms on tasks and activities related to the district wide math school curriculum.

Population / Participants / Subjects:

Participants were comprised of 146 third grade children from public school classrooms in the southwest United States. The final selection was based on parent approval for participation and achievement scores across two years. Of the 146 children selected, 74 were females and 72 were males. Ethnic representation of the sample was 83 Anglo, 30 Hispanic, 13 African American, 8 Asian, and 12 mixed and/or other (e.g., Anglo and Hispanic, Native American). The mean SES of the sample was primarily low SES to middle SES based on free and reduced lunch participation, parent education, and parent occupation. This study used a cut-off score of the 25th percentile on two standardized math achievement tests to determine children at risk for math difficulties. The 25th percentile cut-off score on standardized achievement measures has been commonly used to identify children at risk (e.g., Fletcher, Epsy, Francis, Davidson, Rourke, & Shaywitz, 1989). This procedure separated the sample into 58 children with MD (24 females. 34 males) and 88 children (50 females, 38 males) without MD. Our cut-off criteria for defining children at risk for MD in problem solving was a score above the 35th on measures of fluid intelligence (Raven Colored Progressive Matrices Test), reading (Test of Reading Comprehension, Word Identification subtest from the WRAT-3, Wilkinson, 1993), and calculation (subtests from the WIAT; Psychological Corporation, 1992), but a composite score below the 25th percentile (below a standard score of 90 or scale score of 8) on two standardized problem solving subtests. The story problem subtests were taken from the Test of Math Ability (TOMA, Brown, Cronin, & McIntire, 1994) and Key Math (Connolly, 1998).

Intervention / Program / Practice:

Each experimental treatment condition included 20 scripted lessons administered over 8

weeks. Each lesson was 30 minutes in duration and was administered three times a week in small groups of 3 to 5 children. Lesson administration was done by one of six tutors (doctoral students). Children were presented with individual booklets at the beginning of the lesson, and all responses were recorded in the booklet. Each lesson within the booklet consisted of four phases: warm-up, instruction, guided practice, and independent practice. The warm-up phase included two parts: calculation of problems that required participants to provide the missing numbers (9+2=x, x+ 1=6; x-5=1) and a set of puzzles based on problems using geometric shapes. This activity took approximately 3 to 5 minutes to complete. The instruction phase lasted approximately 5 minutes. At the beginning of each lesson, the strategies and/or rule cards were either read to the children (e.g., to find the whole, you need to add the parts) or reviewed. Depending on the treatment condition, children were taught the instructional intervention (Verbal Strategy, Visual Strategy, or Verbal Strategy + Visual Strategy). The steps for the Verbal Strategy-only approach included: find the question and underline it, circle the numbers, put a square around the key word, cross out information not needed, decide on what needs to be done (add/subtract/or both) and solve it. For the Visual Strategy-only condition students were taught how to use 2 types of diagrams. The first one represented how parts made up a whole. The second type of diagram represented how quantities were compared. The diagram consisted of 2 empty boxes, one bigger and the other smaller, at which students were to fill in the correct numbers representing the quantities. An equation with a question mark was presented. The question mark acted as a placeholder for the missing number provided in the box. Finally, for the combined Verbal + Visual Strategy condition, an additional step (diagram) was added to the 6 Verbal Strategy steps described above. This step included directing students to fill in the diagram with given numbers and identify the missing numbers in the corresponding slots in the boxes. The third phase, *guided practice*, lasted 10 minutes and involved students working on three practice problems. Tutor feedback was provided on the application of steps and strategies to each of these three problems. In this phase, students also reviewed problems from the examples from the instructional phase. The tutor assisted students with finding the correct operation, identifying the key words, and providing corrective feedback on the solution. The fourth phase, *independent practice*, lasted 10 minutes and required students to independently answer another set of three word problems without feedback. If the student finished the independent practice tasks before 10 minutes were over, they were presented with a puzzle to complete. Student responses were recorded for each session to assess the application of the intervention and problem solving accuracy. Treatment fidelity was assessed each week by two independent observers and yielded above 95% rating across all strategy conditions.

Research Design:

The criterion measures used to assess treatment effects were word problems from the Comprehensive Math Abilities Test (CMAT), arithmetic problems from the WRAT-3, and recall from an Operation Span measure. Equivalent forms were developed for each measure and counterbalanced across treatment conditions. Children were randomly assigned at the individual level within each classroom to either a control group (N = 38) or to one of three treatment conditions [Verbal Strategies (N = 37), Verbal + Visual Strategies (Diagramming; N = 35), and Visual Strategies-only (Diagramming; N = 36)] Although the participating children were randomly assigned to each of the different strategy conditions within classrooms, a number of other controls were built into the implementation of the intervention. For example, to control for the impact of the graduate student tutors who implemented the interventions, all tutors were

randomly rotated across days of the week and across treatment conditions, so that no one intervention group received instruction from the same graduate tutor each time (i.e., " tutor 1" might have presented Strategy A in the morning timeslot on Monday, but then "tutor 2" presented the next Strategy A lesson to the same children during that timeslot on Wednesday). When comparing demographics of the children randomly assigned to one of the four treatment conditions (verbal-only, verbal+visual, visual-only, control), no significant differences emerged between conditions as a function of MD status, $\chi^2(3, N = 146) = 2.02, p > .05$; or gender, $\chi^2(3, N = 146) = 1.04, p > .10$; or chronological age, $F(3, 142) = 1.38, p > .05$, or WMC, $F(3, 142) = 1.00, p > .05$. WMC was determined for each participant and was the composite score of performance on three working memory measures (conceptual span, updating, digit/sentence span).

Data Collection and Analysis:

The data reflected treatments of children nested within classrooms, and therefore a mixed ANCOVA model was computed to analyze treatment effects. Because we assumed that post-test comparisons among treatment conditions would depend on the level of WMC, a covariate (WMC) by treatment interaction model was computed (e.g., Leon et al., 1998; Littell et al., 2010, p. 267-273) .The fixed and random effect parameter estimates for this model were obtained using PROC MIXED in SAS 9.3 (SAS Institute, Inc, 2008). The criterion variables in the analysis were posttest scores (adjusted for pretest) for solution accuracy (Story problems-Comprehensive Math Abilities Test-CMAT), calculation accuracy (WRAT-3), and operation span. The factorial design for the study was a 2 (risk group: children with and without MD) x 4 (treatment condition) ANCOVA analysis on post-test scores with covariates of pretest accuracy and pretest WMC. To provide an appropriate analysis the interaction, three values (levels) of WMC were compared among treatment outcomes. These levels included the mean WMC value for the total sample at pretest, followed by an analysis of low WMC and high WMC values. Each of these values of WMC compared treatment outcomes on post-test scores adjusted by their pretest value.

Findings / Results:

Table 1 (appendix B) shows post-test outcomes by ability group,treatment and WMC level for each criterion measure. Table 2 shows the effect sizes for adjusted post-test scores as a function of treatment and WMC level for the three criterion measures. For the primary measure (CMAT solution accuracy), a 2 (MD vs. NMD) x 4 (treatment) mixed model ANCOVA was computed. Pretest CMAT solution accuracy and WMC were included in the analysis. A significant effect emerged for the treatment x WMC interaction, $F\ (3,140) = 4.25$, $p < .01$ and the pretest CMAT score, $F\ (1,140) = 76.70$, $p < .001$. The risk x treatment x WMC interaction approached significance, $F\ (3,140) = 2.19$, $p < .10$. No other significant effects emerged (all *p*s >. 10).

To provide an appropriate analysis of the unequal slopes (as reflected in the WMC interaction), the level of WMC at pretest were set to 1/2 standard deviation above the mean (z=.50) and 1/2 standard deviation(z=-.50) below the mean scores for the total sample. For the low WMC level, the adjusted z-post-test means (collapsed across ability group) were .26, .59, .36, and .75 for verbal-only, verbal+visual, visual-only and control conditions, respectively. Post-test scores were higher for the control condition than the strategy conditions. For the high pretest WMC level, the adjusted means (collapsed across ability group) were .68 ,.39, 1.12 and .26 for verbal-only, verbal+visual, visual-only and control conditions, respectively. A Tukey test comparing the means yielded significant differences (*p*s < .05) in adjusted mean scores in favor of the visual-only condition (visual-only > verbal-only = verbal+visual=control). We recomputed

this analyses by entering pretest measures of reading, calculation and fluid intelligence (Raven) in the mixed regression. The results indicated reading (composite of TORC and WRAT), arithmetic (WIAT) and fluid (Raven) intelligence did not interact with treatment conditions, all *p*s > .10. More importantly, the significant treatment x WMC interaction was retained, $F(3,139)=5.39$, $p < .01$. Figure 1 (appendix B) shows the estimated post-test scores for treatment condition (visual-only) and the control condition. In general, the results support the notion that strategy conditions facilitate problem solving when the regression line is set to a relatively high WMC level.

A similar analysis was computed on post-test measures of calculation and operation span. Significant ability group x treatment x WMC interactions occurred on both these criterion measures. The effect sizes are reported in Table 2. The important finding was that children with MD and high WMC in the visual-only conditions superseded their peers. No advantages were found for children with low WMC in the strategy conditions.

Conclusions: This study investigated the role of strategy instruction and WMC on word problem solving accuracy and transfer measures in children with MD. The results showed a significant WMC x treatment interaction across all criterion measures. In general, the results indicated that WMC played an important role in post-test performance outcomes, especially for the strategy conditions that included diagramming (visual-only condition). The results fit a model suggesting that training in cognitive strategies were more likely improve problem solving outcomes for children with a relatively larger WMC because these children have spare WM sources to effectively utilize these strategies. There are, however, at least two qualifications to the results.

First, the potential moderating effects of WMC may change with longer interventions periods. Models of skill acquisition (e.g., Ackerman, 1988) suggest that WMC may be important in the early phases of skill acquisition, but become less important with longer interventions and the implementation of strategies is automatized. Second, children without MD did not benefit from strategy conditions on posttest measures of solution and calculation accuracy, but benefited from strategy conditions on the posttest operation span measure. One possible explanation was that the operation span measure was a novel measure and the strategy conditions may have provided some practice in working memory. It may also be the simple case, however, that because basic calculation was involved in the training, and because calculation was embedded in the operation span measure, this may have accounted for the transfer effects.

Our findings have three applications to current research. First, the study may account for why some children benefit from strategy instructions and others do not. We found that a key variable in accounting for the outcomes was WMC. Clearly, WMC would not be the only variable across studies to account for the outcomes; however, the role of WMC in this study appeared to be fairly robust. Second, visual-spatial strategies were found to facilitate problem solving for children with MD and may reduce some of the performance gaps of their normal achieving peers. Our findings are interesting in that several studies have suggested that visual-spatial WM (represented by the visual-spatial sketchpad) is closely linked with MD (e.g., Bull, Epsy, & Weibe, 2008). Our findings do suggest, however, that visual strategies rather than verbal strategies are an important route for strategy training. A final application relates to improvement on a norm-referenced test. The majority of intervention studies for problem solving have shown gains on experimental measures and less so on standardized measures (Powell, 2011). Thus, we were able to improve performance substantially on materials related to standardized tests.

Appendices

Appendix A. References

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Appendix B. Tables and Figures

Not included in page count.

Table 1

Post-Test z-Scores Adjusted for Pretest and the Level of the Working Memory Capacity Covariate

	Mean WMC Level Adj Mean	SE	Low WMC Level Adj Mean	Level SE	High WMC Level Adj Mean	SE	Difference
			Problem Solving Accuracy				
Verbal-Only							
MD	0.64	0.41	0.34	0.19	0.82	0.59	.48
NMD	0.40	0.15	0.19	0.25	0.53	0.14	.34
Verbal+Visual							
MD	0.12	0.34	0.54	0.18	-0.06	0.5	-.60
NMD	0.76	0.22	0.65	0.37	0.84	0.16	.19
Visual-Only							
MD	1.04	0.37	0.2	0.18	1.5	0.51	1.30
NMD	0.66	0.17	0.54	0.26	0.75	0.15	.21
Control							
MD	0.01	0.38	0.44	0.16	-0.19	0.54	-.63
NMD	0.82	0.17	1.06	0.31	0.72	0.14	-.34
			Calculation				
Verbal-Only							
MD	1.51	0.45	1	0.2	1.8	0.64	.80
NMD	1.41	0.16	1.29	0.27	1.5	0.14	.21
Verbal+Visual							
MD	1.42	0.36	1.07	0.18	1.62	0.54	.55
NMD	0.96	0.24	0.38	0.4	1.29	0.18	.91
Visual-Only							
MD	2.22	0.4	0.85	0.19	2.94	0.56	2.09
NMD	1.14	0.18	1.07	0.28	1.2	0.16	.13
Control							
MD	0.56	0.42	1.05	0.17	0.35	0.6	-.70
NMD	2.19	0.18	2.3	0.34	2.17	0.15	-.13
			Operation Span				
Verbal-Only							
MD	0.54	0.37	0.39	0.16	0.61	0.53	.22
NMD	0.53	0.13	0.5	0.22	0.55	0.11	.05
Verbal+Visual							
MD	0.28	0.31	0.25	0.15	0.3	0.47	.05
NMD	0.5	0.19	0.49	0.33	0.51	0.15	.02
Visual-Only							
MD	1.08	0.3	0.62	0.15	1.31	0.41	.69
NMD	0.89	0.14	1.06	0.21	0.81	0.12	-.25

Control							
MD	0.07	0.35	0.41	0.14	-0.1	0.49	-.51
NMD	0.19	0.14	-0.34	0.27	0.45	0.12	.79

Adj=adjusted mean, WMC=Working memory capacity; Low WMC= regression line for WMC set to -.50 z-score, High WMC=regression line for WMC set to +.50 z-score
Difference= High minus low WMC regression line.

Table 2

Effect Sizes for Adjusted Post-Test Scores as a Function of Treatment Conditions within Ability Groups

		Math Difficulties			Average Achievers		
Mean WMC		CMAT	WRAT	Op. Span	CMAT	WRAT	Op. Span
Verbal-Only[a]							
vs.	Verb+Vis	0.37	0.06	0.2	-0.43	0.49	0.04
vs.	Visual	-0.29	-0.46	-0.45	-0.34	0.33	**-0.55**
vs.	Control	0.43	**0.59**	0.35	**-0.54**	**-0.95**	**0.52**
Verbal+Visual[a]							
vs.	Visual	**-0.66**	**-0.54**	**-0.67**	0.12	.-.19	**-0.53**
vs.	Control	0.08	**0.54**	0.16	-0.07	**-1.32**	0.42
Visual-Only[a]							
vs.	Control	**0.71**	**1.04**	**0.80**	-0.2	**-1.24**	**1.07**
Low WMC							
Verbal-Only[a]							
vs.	Verb+Vis	-0.29	-0.1	0.24	-0.32	**0.59**	0.01
vs.	Visual	0.21	0.21	-0.41	-0.28	0.17	**-0.54**
vs.	Control	-0.15	-0.07	-0.04	**-0.64**	**-0.68**	**0.71**
Verbal+Visual[a]							
vs.	Visual	0.48	0.3	**-0.63**	0.08	-0.45	-0.47
vs.	Control	0.14	0.03	-0.27	-0.27	**-1.17**	**0.62**
Visual-Only[a]							
vs.	Control	-0.37	-0.29	0.37	-0.39	**-0.84**	**1.23**
High WMC							
Verbal-Only[a]							
vs.	Verb+Vis	0.43	0.08	0.16	-0.45	0.29	0.07
vs.	Visual	-0.34	-0.53	-0.41	0.31	0.41	-0.47
vs.	Control	0.48	**0.63**	0.37	-0.28	**-0.95**	**0.18**
Verbal+Visual[a]							
vs.	Visual	**-0.79**	**-0.61**	**-0.58**	0.13	0.12	**-0.50**
vs.	Control	0.06	**0.55**	0.21	0.18	**-1.2**	0.1
Visual-Only[a]							
vs.	Control	**0.83**	**1.15**	**0.80**	0.04	**-1.33**	**0.64**

Note. [a] =positive ES in favor this treatment, Bold=effect sizes at or above .50.
CMAT=story problems from the Comprehensive Math Abilities Test, WRAT=Arithmetic problems from the Wide Range Achievement Test, Op. Span= Item recall accuracy from the Operation Span Measure.
ESs were computed on adjusted post-test means with WMC set at the average sample level, followed by setting the covariate level to low (-.50 z-score), and high WMC pretest levels.

Hedge's g = γ / $[(SE_1^2)(N_1) + (SE_2^2)(N_2)/ 2]^{1/2}$, was calculated where γ is the HLM coefficient for the intervention effect, which represents the mean difference between treatment adjusted for both level-1 and level-2 covariates, N_1 and N_2 are the sample sizes, and SE_1 and SE_2 are the standard errors for the comparison condition, respectively. The level-2 coefficients were adjusted for the level-1 covariates under the condition that the level 1 covariate (pretest) was grand mean centered.

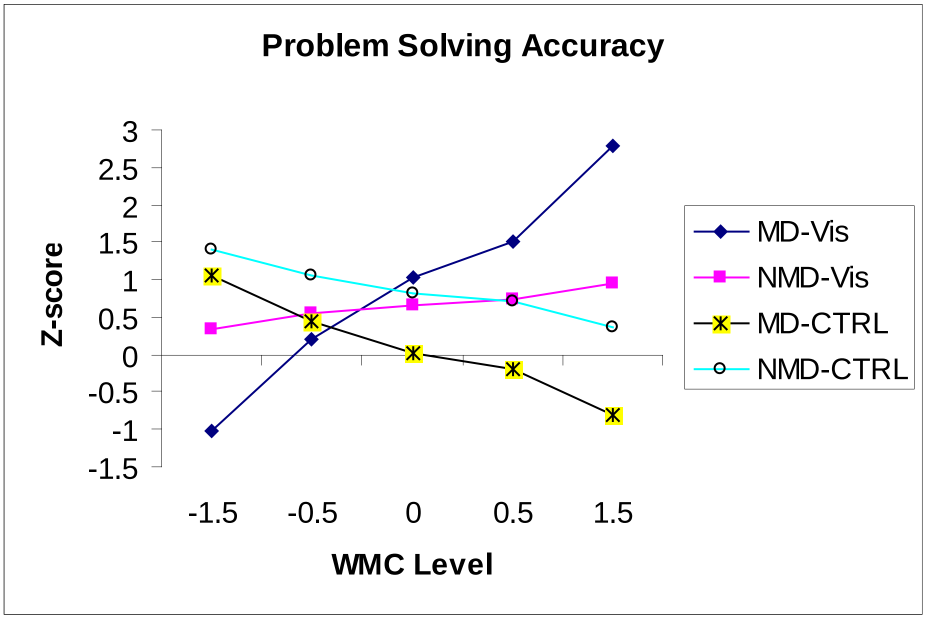

Figure 1. *A comparison of children with math difficulties (MD) and without math difficulties (NMD) as a function of Visual-only condition (Vis)* and control (CRTL) condition at the level of the pretest working memory capacity (WMC) score